JPL

Information Technologies & Software Systems

"Bringing the Space Age into the Information Age."

Dr. Richard J. Doyle, Mgr.
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Our intellectual directions:

- Mission Information Systems
  Complete, seamless, flexible and reusable mission software and data systems for JPL's deep space exploration missions
- Software Engineering
  State-of-the-art tools, techniques, processes and practices for cost-effective, predictable, repeatable development of the highest quality mission software systems
- Revolutionary Operations
  Customized, distributed mission operations systems and concepts for scientists and engineers to accomplish JPL's deep space exploration missions
- Revolutionary Engineering
  Information technologies, infrastructure and computing environments to enable continuous improvements in the quality and productivity of engineering for space systems
- IT Communications
  The premiere computer networking for engineering and operations of deep space missions, from the Deep Space Network to Mars Network and beyond
- Autonomy for In-Situ Science
  Onboard intelligence to plan and control space platforms interacting with remote planetary environments, for on-site exploration and discovery, especially the search for life
- Breakthrough Computer Science
  Research and development in information and computing technologies to enable revolutions in the application of computer science principles to deep space exploration

We have four Sections:

- Engineering and Communications Infrastructure (366)
  Collaborative engineering, virtual environments, supercomputing, modeling and simulation, high-speed networking

  Dr. Larry A. Bergman, Mgr.
  Larry.A.Bergman@jpl.nasa.gov

- Exploration Systems Autonomy (367)
  Artificial intelligence, automated planning and scheduling, control executives, data mining, quantum computing, biocomputing

  Dr. Anna M. Tavormina, Mgr.
  Anna.M.Tavormina@jpl.nasa.gov

- Mission Execution and Automation (368)
  Mission operations systems, operations automation, ground data systems, intelligent data management, data visualization tools

  Mr. David M. Nichols, Mgr.
  David.M.Nichols@jpl.nasa.gov

- Mission Software Systems (369)
  Software architectures, software systems engineering, mission data systems, middleware, distributed computing

  Dr. Roger A. Lee, Mgr.
  Roger.A.Lee@jpl.nasa.gov

Time	366	367	368	369
2-4 PM	SETUP		SETUP	SETUP
4-5 PM		A. Tavormina, E. Mjoslness, J. Roden	N. Rouquette	Duquette, DeForest, Kirby
5-6 PM	A. Martin	A. Donnellan, A. Tavormina	M. O'Dell or D. Nichols	C. Miyazono, Levesque
6-7 PM	M. Meidinger	A. Tavormina & GSs	J. Patterson	Lee, Larson
7-8 PM	L. Bergman	A. Tavormina & GSs	C. Garcia	Lee, Larson
Support			C. Corrigan	
Section Managers & Deputies:		A. Tavormina, L. Bergman, R. Lee, A. Larson, D. Nichols		
Group supervisors:		L. DeForest, C. Kirby, E. Mjolsness, A. Donnellan		

Information Technologies and Software Systems Division (36)

Dr. Richard J. Doyle, Technical Division Manager
Dr. David J. Atkinson, Deputy Division Manager

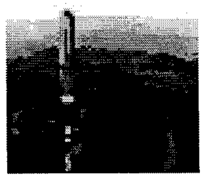
Overview of Technology Work

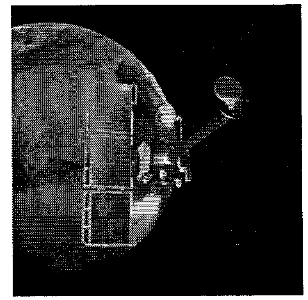
June 28, 2000

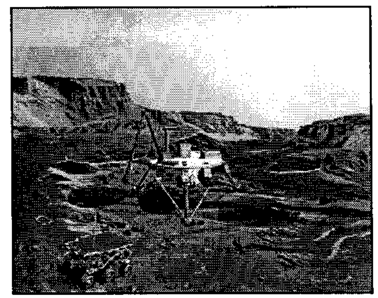
http://it.jpl.nasa.gov

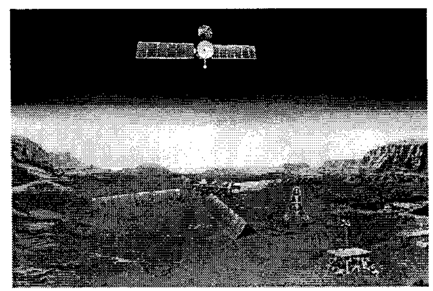
Mars Outposts

- **Remote Science Laboratories**
  - Tele-operated or autonomous laboratories in the planetary environment for handling and conducting in situ scientific investigations on collected samples
- **Three scales / resolutions**
  - remote sensing
  - distributed sensing
  - point sensing
- **Heterogeneous, cooperating networks**
  - distributed networks of sensors, rovers, orbiters, permanent science stations, probes: all of which respond to sensing events, discoveries, changing PI directions, etc., to provide rich presence in Mars environment for science community and public
- **Infrastructure**
  - Planetary permanent infrastructure to support series of science and/or commercial missions leading to human presence

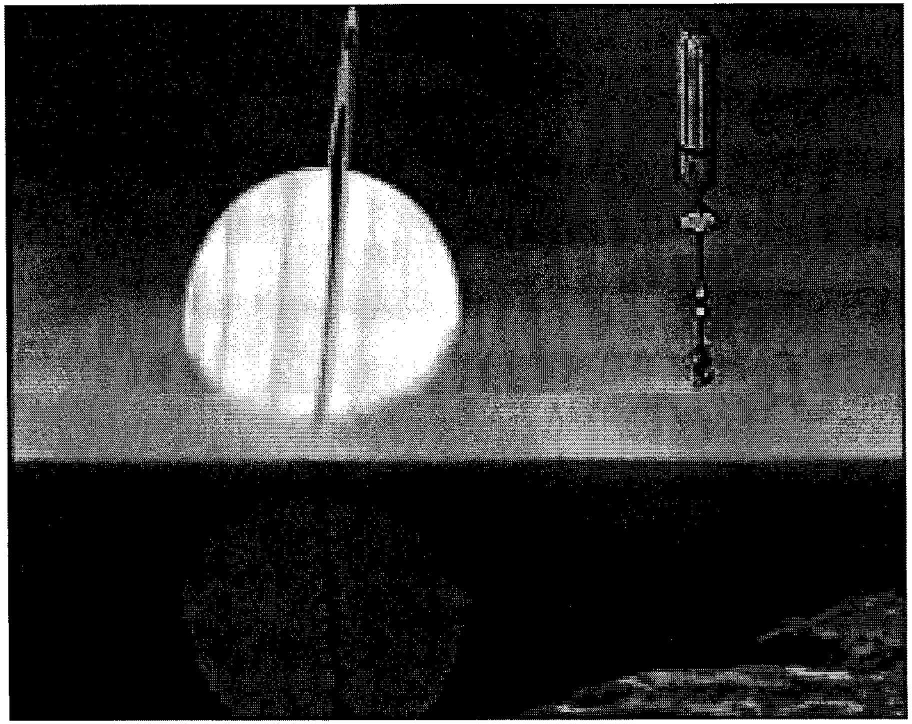






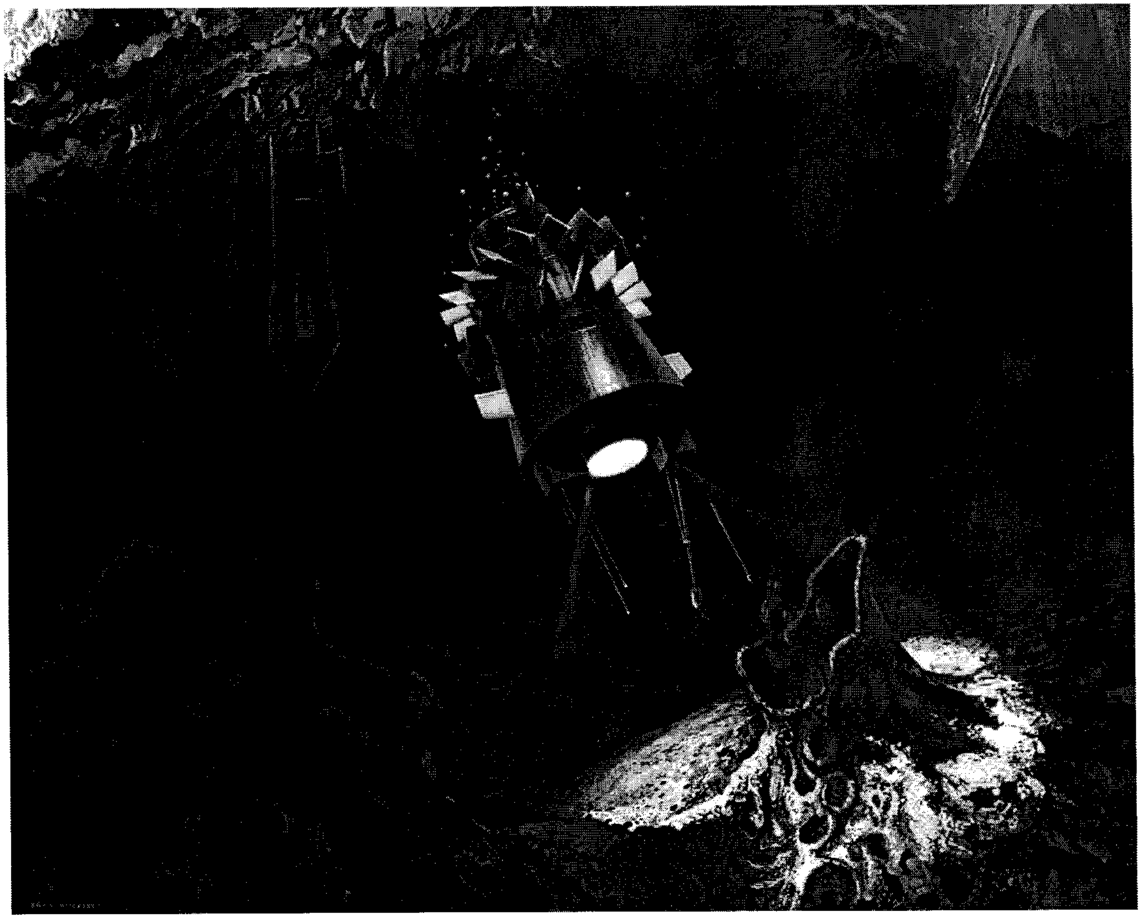


Titan Aerobot



- The aerobot conducts in-situ science operations when landed, and wide-area imaging when aloft.
- Archived and learned models of wind patterns assist path planning, enabling near-returns to areas of high scientific interest.

Europa Cryobot / Hydrobot



- Perhaps more than any other, a mission of discovery in a truly alien environment: How to know what to look for? How to recognize it?

JPL Engineering and Communications Infrastructure Section

Dr. Larry A. Bergman, Mgr; Anthony J. Martin, Dep Mgr

Engineering and Communications Infrastructure (366)

- Collaborative Engineering
- Supercomputing
- Virtual Environments
- Distributed Modeling Tools
- DSN Networking
- Network Infrastructure
- Visualization
- IT Testbeds
- IT Communications

- Thrust Leadership:
  - Revolutionary Engineering
  - IT Communications
- Objective:
  - Provide the premier computing, networking, and IT engineering infrastructure for JPL missions
- Growth Areas:
  - Intelligent synthesis environment
  - Mars & interplanetary networks
  - Virtual environments
  - Virtual testbeds
- Major Customers:
  - NASA, DSN, DARPA, Army

Exploration Systems Autonomy Section

Dr. Anna M. Tavormina, Mgr

Exploration Systems Autonomy (367)

- Onboard Science
- Distributed Spacecraft Algorithms
- Mobile Science Applications
- Biosignature Algorithms
- Quantum Computing
- Executive Cntrl Systems
- Rover Autonomy
- Smart Instruments
- Data Mining
- Planning & Scheduling tools

- Thrust Leadership:
  - Autonomy & IT for In-Situ Science
  - Breakthrough Computer Science
- Objective:
  - Provide the autonomy and computing technologies which enable the next generation of highly autonomous and scientifically-productive deep space missions
- Growth Areas:
  - Surface systems, next-generation computing
  - Smart science instruments
  - Onboard science algorithms
  - Mission planning & scheduling
- Major Customers:
  - NASA, DARPA, Army CoE, ONR

Mission Execution and Automation Section

Mr. David A. Nichols, Mgr; Ms. Bolinda Kahr, Dep Mgr

Mission Execution and Automation (368)

- Mission Control Systems
- Beacon Ops
- Intelligent Data Management
- Collaborative Ops Tools
- Distributed Science Data
- Remote Ops Systems

- Thrust Leadership:
  - Revolutionary Operations
  - Mission Information Systems (supporting)
- Objective:
  - Provide robust and cost-effective mission accomplishment systems and concepts to a broad range of science, mission, and defense customers
- Growth Areas:
  - MDS Adaptation
  - Mission software
  - Mission design, ops concepts
  - Science support
- Major Customers:
  - NASA

Mission Software Systems Section

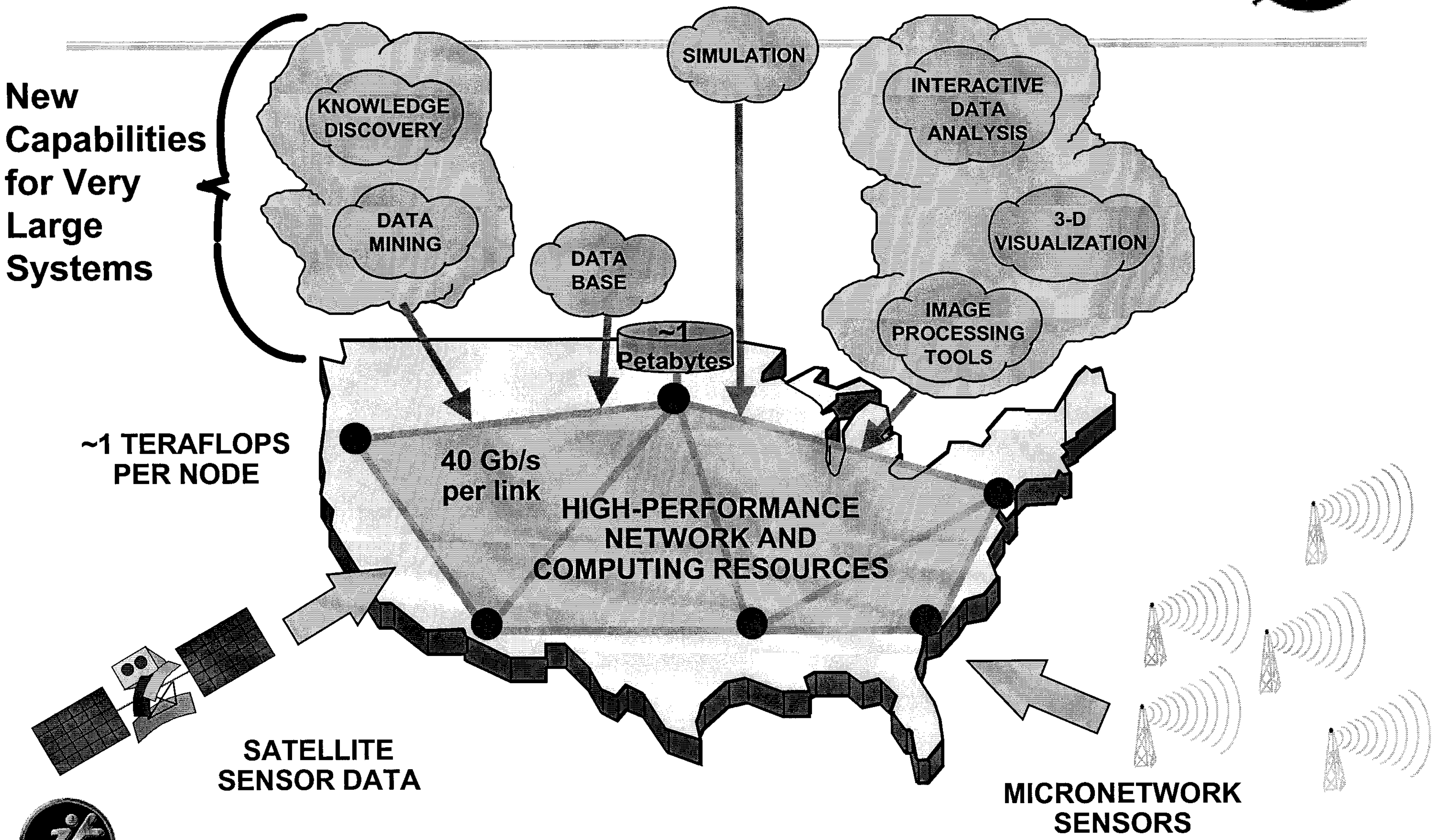
Dr. Roger A. Lee, Mgr, Ms. Annette Larson, Dep Mgr

Mission Software Systems (369)

- MDS Development
- MDS Architecture
- Software System Engineering
- GDS Architecture
- GDS Development
- Software Architectures
- Software Best Practices
- Middleware
- REE

- Thrust Leadership:
  - Mission Information Systems
  - Software Engineering
- Objective:
  - Provide leadership for the Laboratory in the design and development of quality mission software and use of state-of-the-art software practices
- Growth Areas:
  - Mission Data System development
  - Mission software
  - Software engineering technology
  - Software fault tolerance
- Major Customers:
  - NASA, DSN, DISA

Meta-Computing Environment



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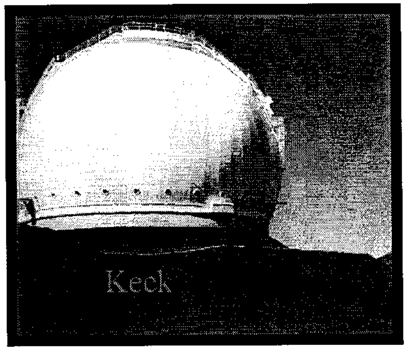
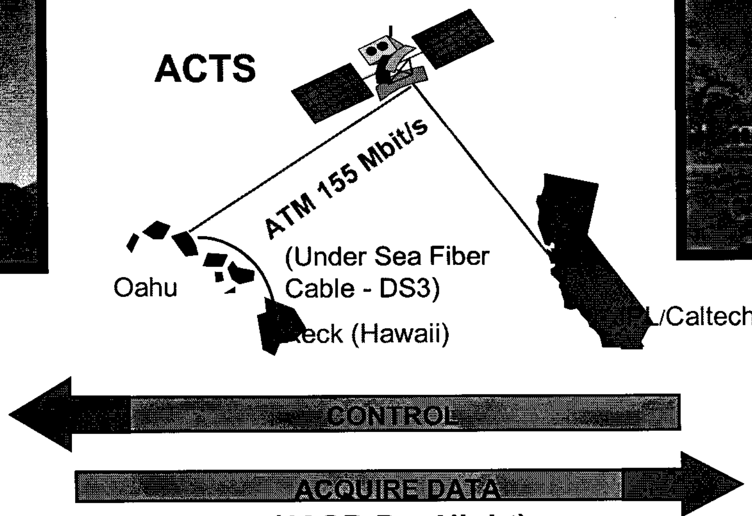
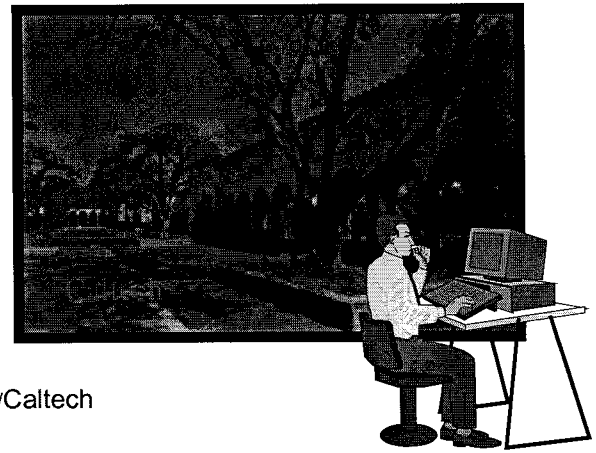
Remote Astronomy at Keck







OBJECTIVES: Validate use of high latency gigabit satellites and network protocol for remote astronomy.

MOTIVATION: High altitude (14,000 ft), long travel time points the need for remote astronomy. High bandwidth satellite communications can reach remote locations where optical fiber is unavailable

EXPERIMENT & RESULTS:

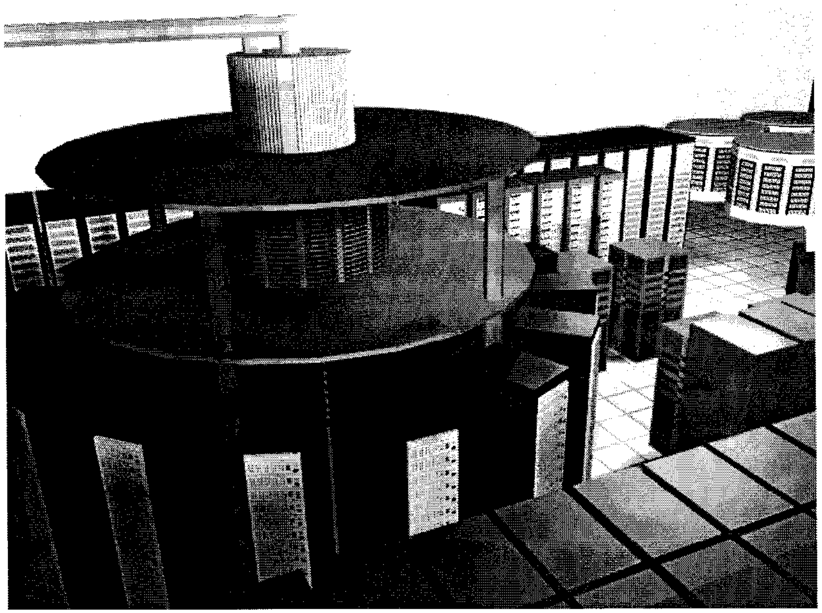
- In Oct 96, LRIS (4Kx4Kx16bit) instrument operated via X-windows control application at Caltech Sun Workstation.
- 15 Mb/s throughout obtained with extended TCP/IP windows, but suffered slow rampup in speed.

SIGNIFICANCE: Remote astronomy via satellite is practical, but more efficient long latency, high bandwidth network protocols are needed.

HTMT Petaflops Computer

GOALS AND OBJECTIVES

- Enable practical and effective Petaflops scale computing within a decade.
- Dramatically improve efficiency, generality, and programmability over today's supercomputers



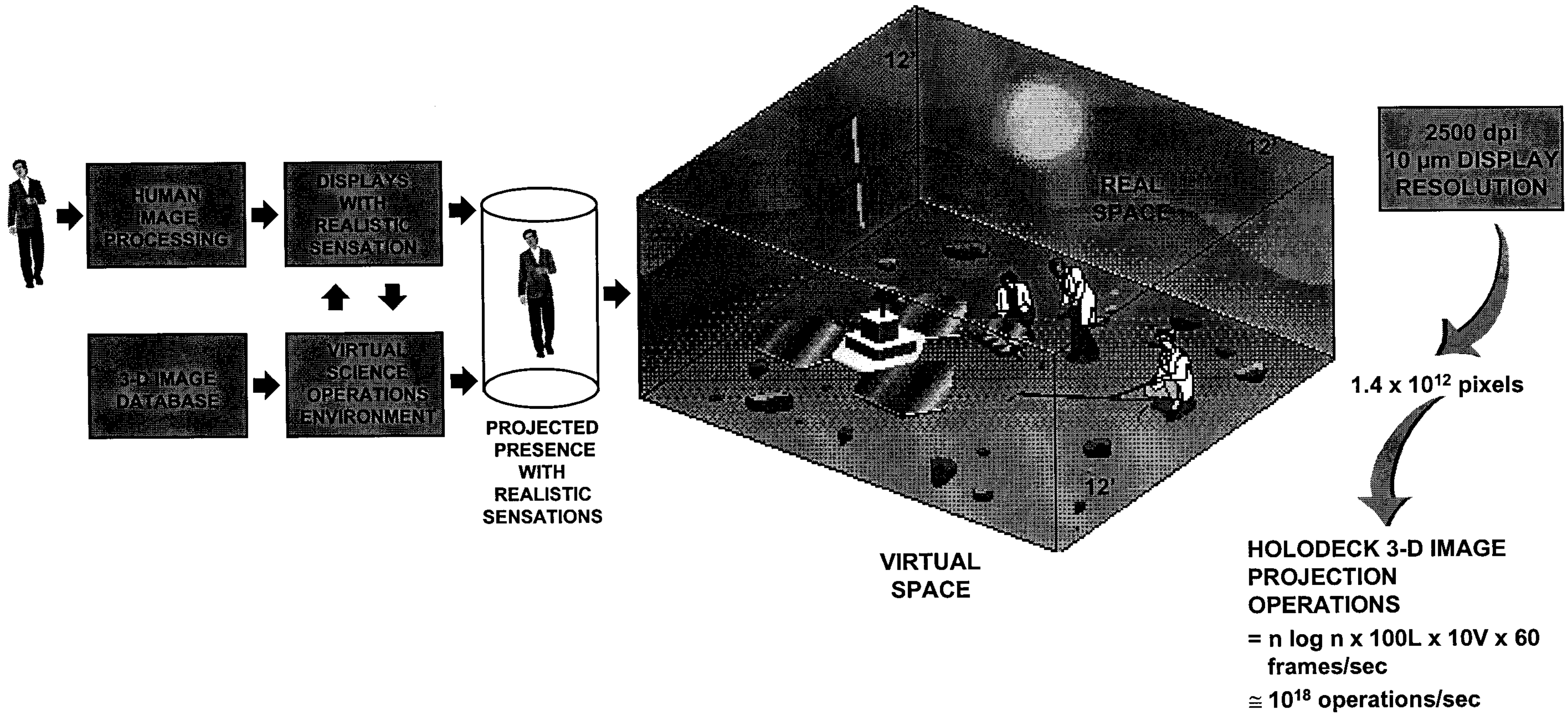
INNOVATIVE TECHNOLOGIES

- Low power high speed (200GHz) RSFQ superconductor logic
- Smart processor-in-memories (PIM)
- Holographic intermediate (3/2) storage between disk and DRAM
- Advanced optical communications

ARCHITECTURE APPROACH

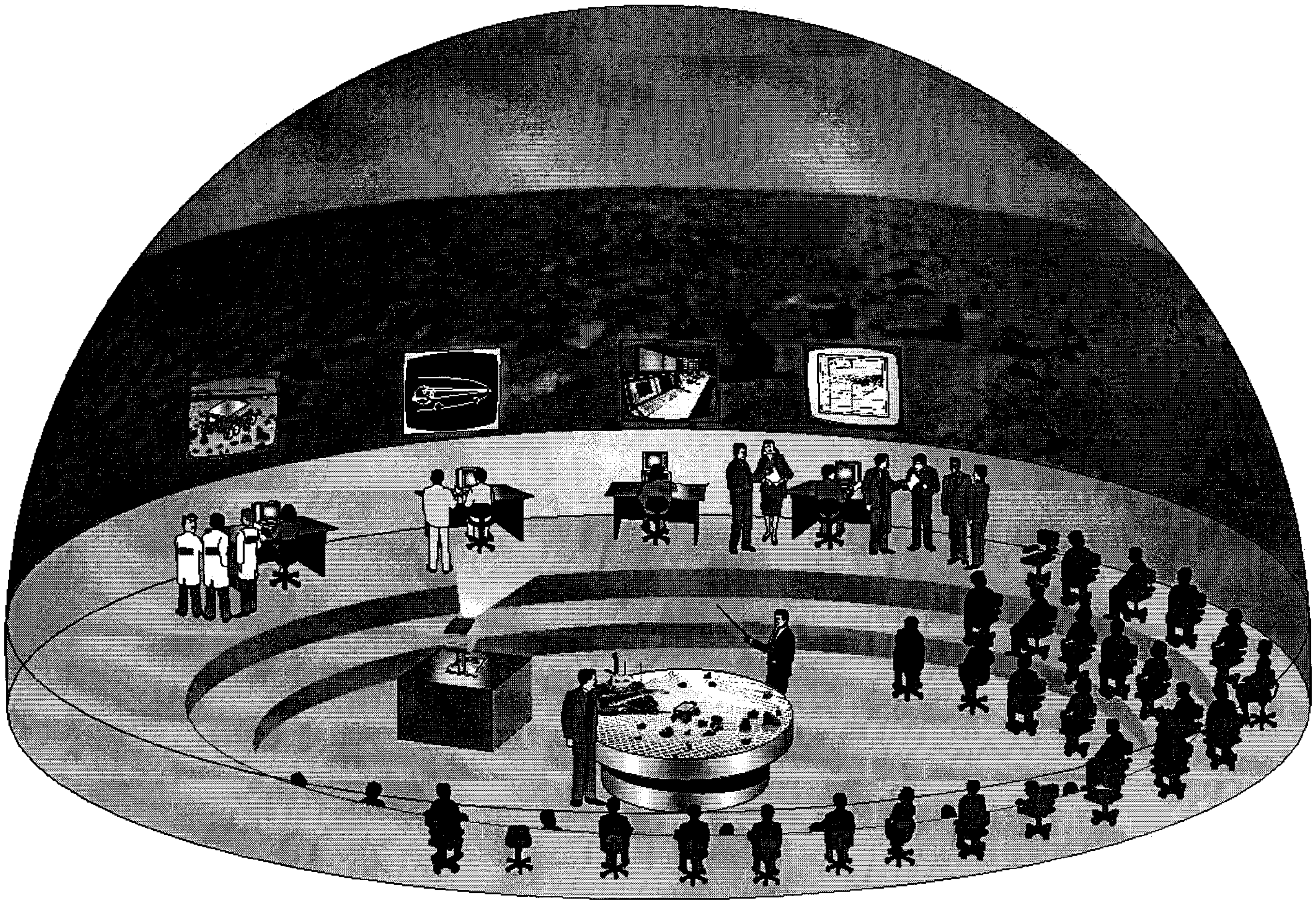
- Very high speed processors for reduced concurrency
- Merges diverse technologies to leverage complementing strengths
- PIM memory architecture for reduced communications bandwidth
- Multithreaded execution model for latency management & high efficiency

Virtual Science Operations



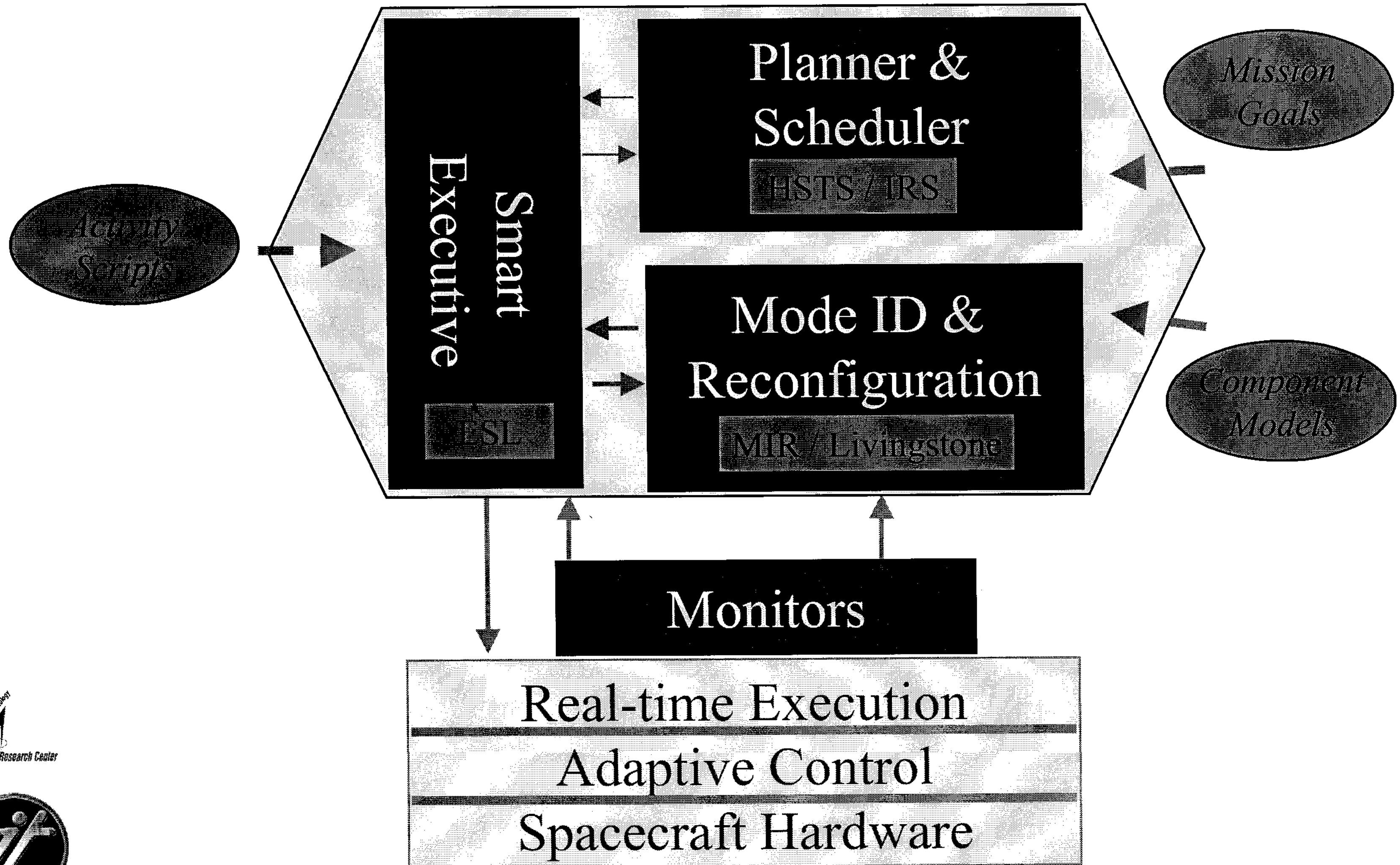
- NO HEAD GEAR FOR 3-D VISUALIZATION
- PHOTOGRAPHIC PROJECTION QUALITY

Mission Dome

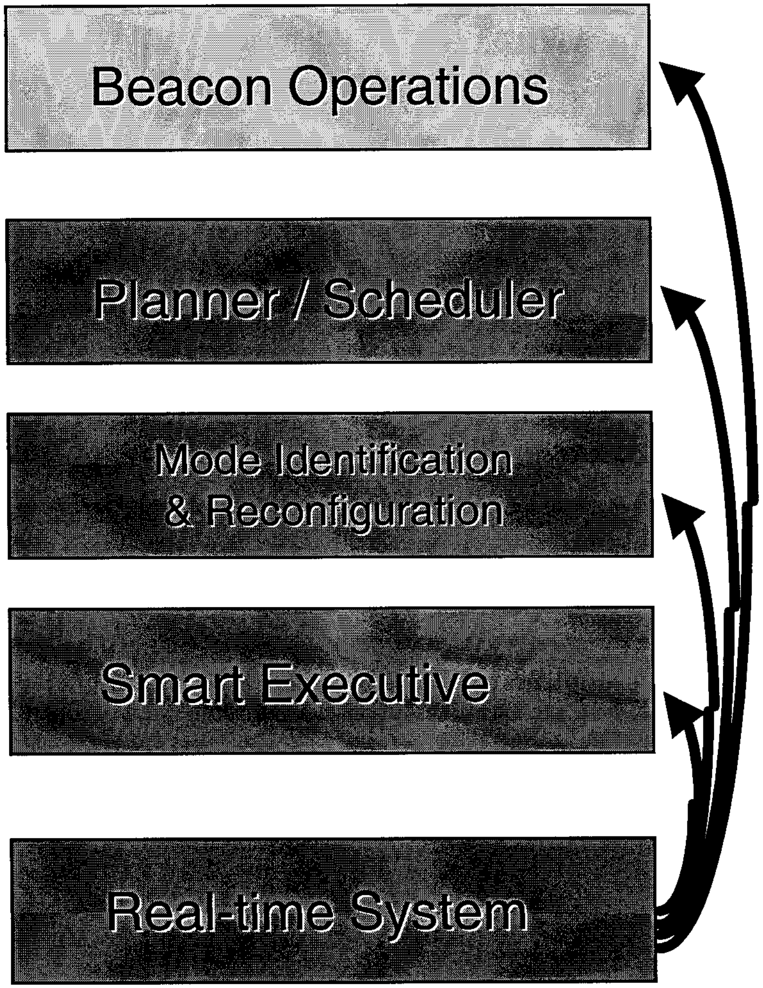


End-to-end Virtual Environment for Mission Lifecycle

Remote Agent Architecture



Closing Loops Onboard



Ground assistance invoked with focused report on spacecraft context and history

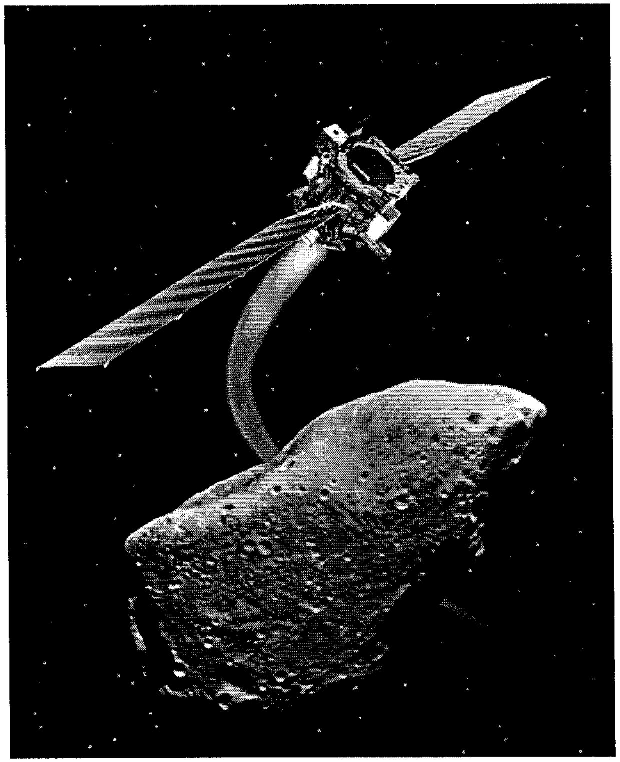
Replanning of mission activities around altered resources or functions

Diagnosis of faults and informed selection of recovery actions

Local retries or alternate, pre-defined activities to achieve same goal

Several layers of onboard recovery provides for unprecedented robustness in achieving mission goals in the face of uncertainty

Remote Agent Experiment



- DS-1 has encountered an asteroid and will encounter a comet.
- Remote Agent Experiment (RAX) achieved 100% of its technology demonstration goals in May '99.
- RAX joined 11 other DS-1 technology experiments such as onboard optical navigation and solar electric propulsion.
- Remote Agent co-winner of 1999 NASA Software of the Year Award

JPL

Autonomy Software Validation

commands → **_Traditional sequenced spacecraft as a <u>transaction</u> system_**

telemetry ←

Send command sequence.

Does the resulting telemetry match predictions?

commands ····→ **_Autonomous closed-loop <u>control</u> system_**

telemetry ←

Observe behavior in the loop.

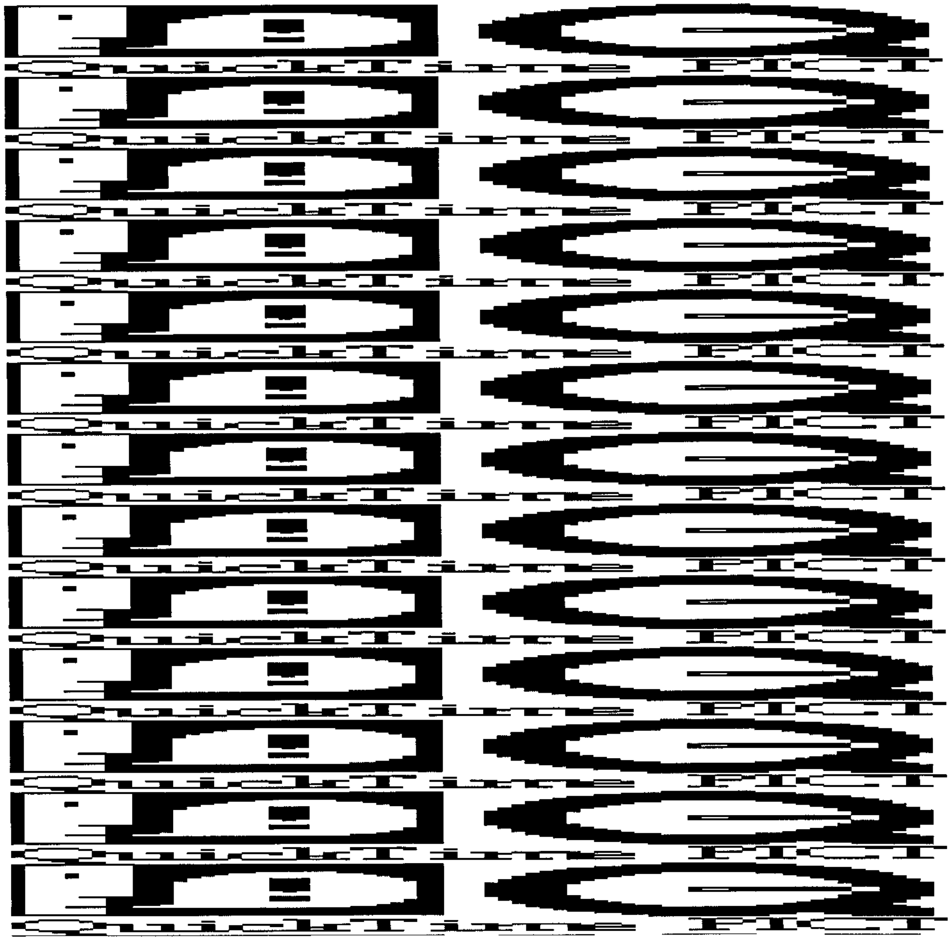
Is the system accomplishing its goals and respecting flight rules in spite of anomalies?

<u>Key idea</u>: (borrowed from model-based fault diagnosis)

- Do not attempt to enumerate all possible s/w failures
- Rather, define and identify departures from acceptable bounds on software behavior
- Apply at design, test and run time

<u>Formal methods</u>-based approaches corrected errors in RA code

QuakeFinder



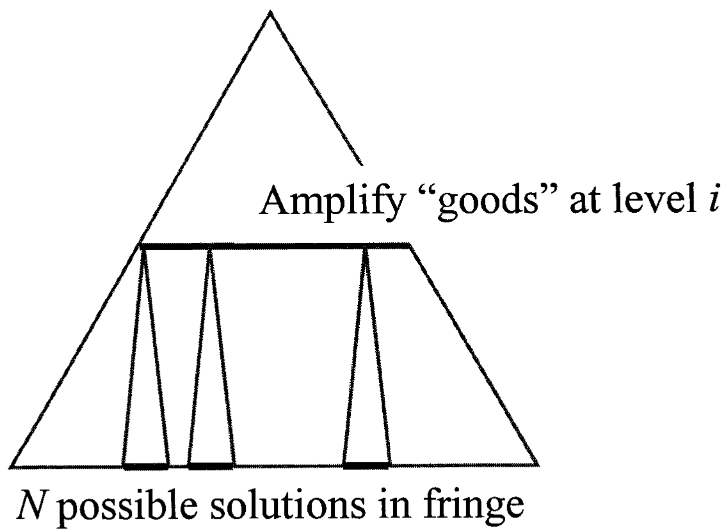
Landers Earthquake, June 1992

- Color wheel shows direction of ground motion.
- 2050x2050 10m pixels
- Displacement map computation increases effective resolution for motion detection to 1-2m
- Hue discontinuity shows movement due to fault (black line).
- Can be extended to process several images, and for general change detection.
- Applications being pursued for Europa and comet lander missions.

Nested Quantum Search

- NP-hard problems (constraint satisfaction, scheduling, planning, VLSI layout etc)
- Previous best quantum algorithm (Grover) had complexity $O\sqrt{N}$
- Ours is $O\sqrt[3]{N}$ for the hardest instances
- Innovation: the use of problem structure to focus quantum search

How it Works



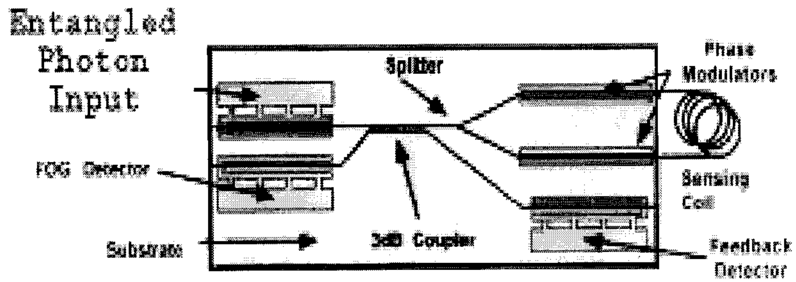
Extend search from just the "goods" at level i

Quantum Optical Gyroscope

Innovation

- Entangled Photons Replace Classical Light
- Quantum Effects Give Eight Order Improvement
- Proven Fiber Optic Technology
- Paradigm shift in Inertial Sensing
- Quantum Mechanics over Classical Mechanics

Ultra-Precision Optoelectronic Chip



Change in the Phase Sensitivity

$$\Delta\phi_{\min} \propto \frac{1}{\sqrt{N}}$$

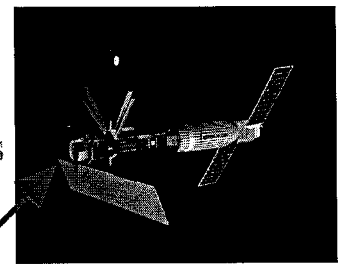
Photon number scaling law for "classical" two-port gyro.

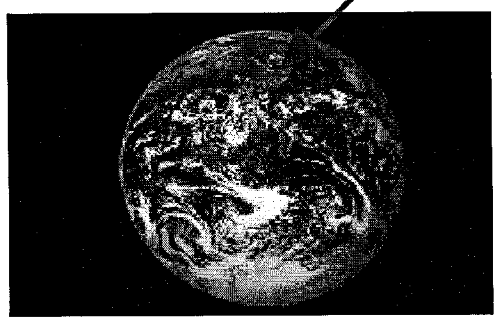
$$\Delta\phi_{\min} \propto \frac{1}{N}$$

Photon number scaling law for quantum two-port gyro.

Inertial Navigation

- Space Exploration
- Under Sea Navigation
- Commercial Applications





Missions

- General Relativity
- Deep Space
- Asteroid Surveying

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Automated Quantum Circuit Design

<u>Technical challenge</u>

Compile desired unitary matrix into a quantum circuit that implements it

<u>Technical approach</u>

Genetic programming plus partial gradient descent

Target algorithm = unitary matrix

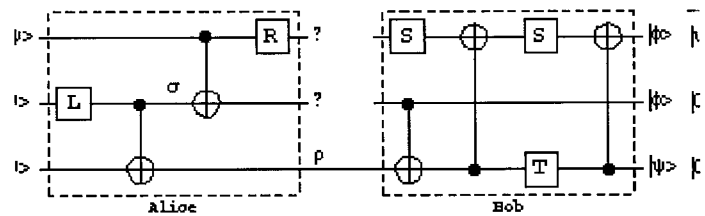
Create population of random circuits

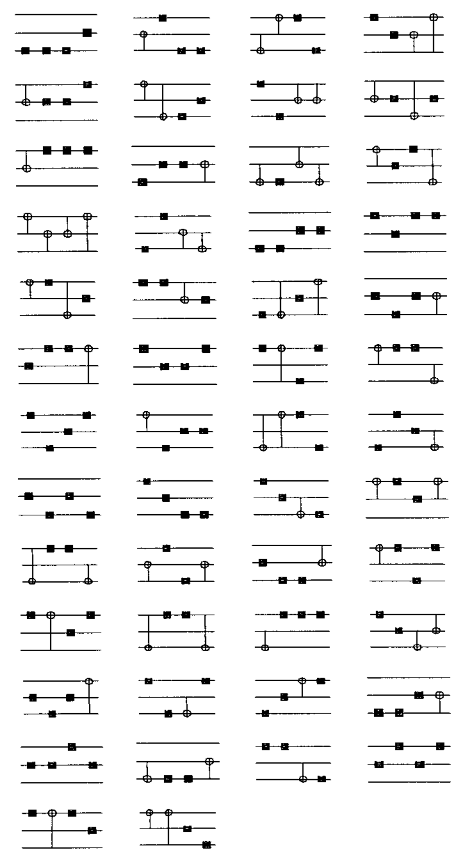
Define fitness based on closeness of operator that the circuit implements to the desired target operator

Select parents, mate & mutate

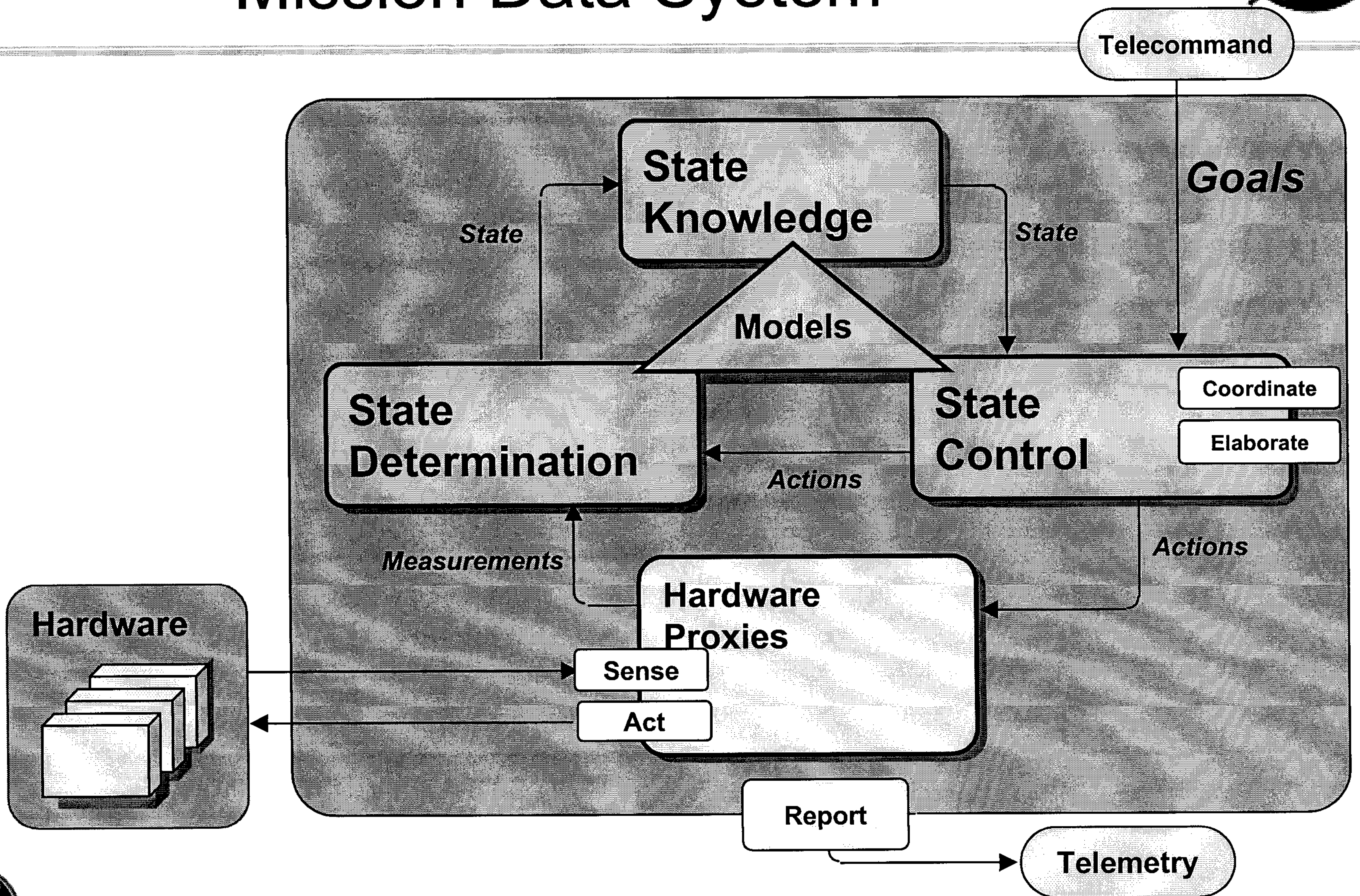
<u>Innovations</u>

"Over-complete" basis gates
Partial gradient descent





Mission Data System



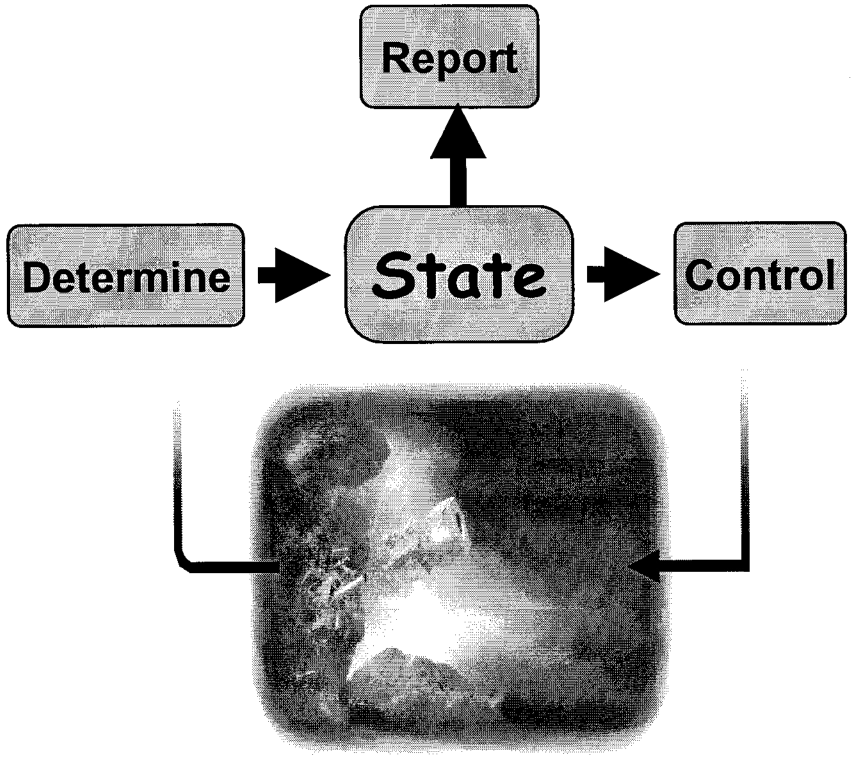
MDS Architectural Themes

- Unifying state-based paradigm behind all elements
- Extensive and explicit use of models
- Goal-directed operations specifies *intent*, simplifies workload
- Closed-loop control enables opportunistic science gathering
- Fault protection is natural part of robust control, not an add-on
- Explicit resource management (power, propellant, memory, etc)
- Navigation and attitude control build from common base
- Clean separation of state determination from control
- State uncertainty is acknowledged & used in decision-making
- Clean separation of data management from data transport
- Upward compatibility through careful design of interfaces
- Object-oriented components, frameworks, design patterns

Theme: State is Central

Definition

- ***State*** is a representation of the momentary condition of an evolving system
- ***Models*** describe how a system's state evolves
- These are what one needs to know
  - To operate a system,
  - To determine or control its future, and
  - To assess its performance



Theme: Goal-Directed Operation

Definition

- A goal specifies *intent*, in the form of *desired state*.
- A *goal* is a constraint on the value of a state variable during a time interval.
- Goal-directed operation is simpler because a goal is easier to specify than the actions to accomplish it.

- Goal-achieving modules (GAMs) attempt to accomplish submitted goals.
- A GAM may issue primitive commands and/or sub-goals to other GAMs.
- A GAM must either accomplish a goal or responsibly report that it cannot.